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DRAWINGS ATTACHED

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(54) CONSTRAINED STRUCTURES

(71) I, LAWRENCE RICHARD BOSCH, a Citizen of the United States of America, of 2285 Ranchera Road, Redding, California, United States of America, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to contrained structures and more especially to such structures formed of a plurality of members restrained from moving in any direction relative to each other. When referring herein to constrained structures I am not limiting to structures for withstanding vertical loads or to structures with members with necessarily parallel axes. The invention, may, therefore, be applied to structures which may be straight, curved, or with members relatively inclined to each other.

In the design of structures the primary criteria is naturally the ability thereof to withstand the type of loading to be experienced. Various other factors such as cost, ease of use and the like are also of importance. A further factor of major importance for many applications is the strength-to-weight ratio. A high strength-to-weight ratio reduces the loading on the structure itself and the loading upon other elements associated therewith so as to be important in all applications. In the field of aircraft structures, for example, it is obviously necessary to minimize weight while maximizing strength, and in substantially all applications wherein elements or structures are either portable or need to be moved, in part or whole, the strength-to-weight ratio is highly important. The present invention is particularly directed to maximizing strength-to-weight ratios.

It is recognized that many structures have been developed which exhibit remarkable strengths under particular types of loading. Thus, for example, honeycomb structures are well known to have very high strength-to-weight ratios for particular applications; and various types of beams formed of lightweight metals, for example, are also highly advanced in this respect. It is, however, equally well recognized that structures of these types are normally intended for limited application in that they have very limited strengths for loadings other than those for which they are designed. Many structures which exhibit very high strengths and strength-to-weight ratios are totally unsuited to the application of bending or torsional forces. The present invention provides a structure having a very high strength for substantially all types of loading.

According to one aspect of the present invention there is provided a constrained structure comprising a plurality of spaced apart elongated members, a compression core between the members in engagement with each of the members over the length of each and having a high compression strength inwardly thereof to prevent the members from moving toward each other, and a tension skin about the members and core and including oppositely wound helical windings of high tensile filament attached to the members to prevent the members from moving away from each other whereby the members are fully constrained from relative motion.

According to a further aspect of the invention there is provided a constrained structure including a plurality of spaced apart elongated members, a compression core comprising a plurality of elongated ribs with one rib being integral with each elongated member along the length thereof with the ribs being joined together along a common joinder line, and a tension skin about the members and core and including oppositely wound helical windings of high tension filament attached to the members to

prevent the members from moving away from each other whereby the members are fully constrained from relative motion.

The present invention provides for the utilization of maximum strength capabilities of the separate elements of the overall structure. It will be seen that the cross-sectional rigidity of the structure is determined by the compressive strength of the core in cross section, as well as the tensile strength of the winding about these elements. It is to be particularly noted that shear forces and torsional forces which may act upon the structure of the present invention are resolved into tensile and compressive forces in the structure. Insofar as the individual members of the structure are concerned, it is possible to liken same to driven piles wherein such piles are constrained from any type of lateral movement so that they are capable of carrying very substantial loads without the danger of buckling.

Such structures are capable of a wide variety of alternative configurations and applications.

Illustrative embodiments of the invention vill now be described with reference to the ccompanying drawings, in which:—

Figure 1 is a schematic prospective illustration of a portion of one form of structure;

Figure 2 is a side elevational view of an embodiment illustrating the oppositely wound tension elements of the structure;

Figure 3 is a partial prospective illustration of a further embodiment incorporating a compression-core unit having four ribs;

Figure 4-A and B are end and side elevations, respectively, of a reinforced rib structure which may be employed, for example, as a portion of a core element;

Figure 5 is an end view of an alternative embodiment incorporating a tubular member as a portion of the core unit of the structure; and

Figure 6 is a side elevational view of a structure having a varying cross-section.

Referring to Figure 1, there is shown a plurality of elongated members 11, preferably formed of uniform cross section, and disposed in fixed relationship to each other. In order to achieve a three-dimensional structure, it is necessary to provide at least three members, although reference is made to subsequent description of a two-column unit as illustrated in Figure 4. The members 11 are adapted to undergo both compressive and tensile loading with the degree thereof depending upon loading of the overall structure. Thus, for example, if the structure is intended only to carry an end load, the individual members would thus only undergo compressive loading lengthwise thereof; however, with other applications such as bridges, beams and the like, both tension and compression loading of these members are involved. Consequently the individual members are designed for their particular application.

The interior of the structure hereof comprises a compression core unit 12 formed of a plurality of ribs 13. There is provided one rib element for each member of the structure, and thus in the embodiment of Figure 1 there are shown to be provided three ribs with each rib continuously contacting a separate member over the length thereof and the ribs all being joined together to extend outwardly from a common contact. This core unit 12 provides continuous support for the members 11 to prevent them from buckling inward toward the centre of the structure. The ribs of the core undergo substantially only compression loading radially inward of the core. It is to be noted that the structure is normally formed with the ribs having a much greater dimension longitudinally of the structure than radially thereof, or, in other words, the length of the individual ribs is substantially greater than the width. Inasmuch as the core element is intended to withstand compressive forces acting inwardly thereon, the individual ribs are so dimensioned as to withstand in excess of the expected compression loading, and in this respect it is noted that the ribs may be thickened between edges thereof to maximize resistance of the ribs to buckling. With regard to the joinder of the ribs, it is noted that they should make good and equal contact with the other ribs of the core and thus for a three-element core, such as shown in Figure 1, each of the ribs would preferably be formed with a v-edge along the centre of the core structure, so that the three ribs would fit together for equal transfer of forces between the ribs. In addition, it is noted that the ribs should be joined together, as by use of appropriate adhesives or other joinder means, depending upon the type of material from which the core is formed. At the outer edges of the core the members are secured to the rib edges, again by appropriate joinder means depending upon the type of materials employed for member and core.

It will be seen that with the members and core, as described above, these members are prevented from moving toward each other by engagement with the compression core unit. The third basic element of the structure, is a tension-skin element (filament winding) 14 wound in tension about the members 11. The skin element 14, as it is hereinafter denominated, is provided in filament form oriented in spiral fashion with approximately one-half of the filament spiraling in one direction along the structure and the other half spiraling in the opposite direction along the structure. The filament

winding of the skin may be formed of a variety of high-tension materials such as fibreglass, wires, steel strap, etc., and the windings of the skin element are placed about the members in tension or, at least, do not have any slack in original condition of application.

In Figure 2 there are illustrated two separate windings 16 and 17 of the skin. It will be seen that this skin element serves to prevent movement of the members away from each other and to firmly hold the members against the compression core unit, so as to thus constrain the members from movement toward or away from each other. Final constraint upon member movement is provided by firmly affixing the skin element 14 to the members, again by the use of appropriate joinder means determined by the materials of the skin and members.

The tension-skin element 14 functions only in tension and with the above-described two-oppositely-wound filaments of the skin, it will be appreciated that the skin actually operates somewhat in the manner of two opposed springs. For most applications, the skin windings are placed sufficiently close together to form a solid skin which may, in fact, be waterproofed, if desired. With a structural element of uniform cross section between the ends thereof, the helix angle α, or filament pitch, of the skin windings will be substantially uniform over the length of the element except at the ends thereof, as illustrated. Various degrees of pitch may be employed; however, it is preferred that the pitch angle lie in the range of 30° to 60° and, for most applications, a pitch angle of 45° is preferable.

It is of interest to note an example of the structure formed from commonly available materials normally considered to have relatively low structural strengths. The members 11 may be formed of wood having the grain running longitudinally thereof, as for example Douglas fir. The core structure, on the other hand, may be formed of a light weight wood having the grain running radially of the ribs between the contiguous column and rib joinder. It is possible to form these ribs of balsa wood, for example, for even this material has a substantial compressive strength longitudinally of the grain. Wound about this wooden core and members is the tension skin 14 which may, for example, be formed of fibreglass filament comprised of two windings of opposite pitch, with the turns of the windings preferably contiguous and suitable bonding, such as a resin or the like, being employed to affix the skin to the members and also the turns of the windings to each other, if desired. An appropriate glue of high strength may be used to join the ribs of the core element together and to the columns, and the completed structure so formed is found to have very remarkable structure properties. One such structure having $1\frac{1}{2}''$ wide ribs of $\frac{1}{8}''$ thickness and members of maximum cross section of $\frac{1}{8}''$ and having $\frac{1}{4}''$ separation between adjacent turns of each winding readily carried a load of 45 lbs. applied at the centre of an 18″ span with the structure supported at both ends. The entire structure in this example weighed less than 2 ounces.

Naturally, the material and size of the individual components of the present structure are chosen in accordance with the design loading of the resultant structure. It will be appreciated that the greater the amount of tension windings provided, the greater strength that will be achieved. Further with regard to these windings, it is noted that when the structure is under load, the windings share the tension skin loads in varying degrees from an equal sharing to an extreme condition of one winding carrying the entire tension load. In a circumstance wherein a torsion load is applied to the structure, it will be appreciated that only one winding spiraling in a particular direction opposing the load will be placed in tension, and the winding spiraling in the other direction would be compression loaded except for the fact that it is flexible and, thus, merely relaxes slightly. It is furthermore to be understood that substantially all loading applied to the structure is resolved into tension and compression forces applied to the separate elements of the structure. Not only are the applied forces resolved into compression and tension forces, but, also, they are applied to particular elements designed to accommodate these loads without failure. It is not, however, intended to state that no possible deflection of a present structure is possible; however, by properly designing an individual structure for a particular application, deflection is minimized to remain less than the elastic limit of the element deflected so that the structure does not fail.

It is, of course, to be appreciated that the structures may be constructed in a variety of different configurations within the basic limitations set forth above. There is illustrated in Figure 3 a four-sided structure, and it will be seen by reference thereto that there are included four longitudinal members 21 which are fixed relative to each other by an internal compression core 22 having four ribs 23 with one engaging each of the members along the inner longitudinal side thereof, and a tension skin 24 about the members. This skin 24 is formed of oppositely wound filaments 26 and 27, and in Figure 3 these windings are shown to be separated in the interest of illustrating the direction of windings. This structure, as

shown in Figure 3, operates in the same manner as that shown in Figures 1 and 2, in that the members 21 are fully constrained against movement relative to each other so that they cannot buckle under either compression or tension. The ribs of the core are subjected substantially only to compression forces applied from the members thereto and transmitted between ribs at the joinder of the ribs. Such forces transmitted from one rib to another will thus be seen to apply forces to other members that, in turn, are taken up by the tension winding, or skin 24. Thus the individual components of the structure are subjected substantially only to tension or compression forces.

It is to be appreciated that the structure of the compression core may be varied somewhat from that illustrated and described above. Thus, for example, there is shown in Figure 4 a two-dimensional member structure that may be advantageously employed as a rib of a compression core.

Referring to this Figure, there will be seen to be provided two longitudinal members, or the like, spaced apart by a compression plate 3. This plate engages the inner side of each of the members 31 and 32 over the entire length thereof, and is primarily designed to withstand compression forces applied thereto through the members. About this member and plate structure there is provided a tension skin 34 formed of two oppositely wound filamentary windings 36 and 37 which are firmly secured to the members in passage thereover. This particular structure, as illustrated in Figure 4 and described above, will be seen to have a very substantial strength except insofar as torsion or bending of the unit are concerned. For certain applications these types of forces are not experienced, and consequently the unit is highly desirable for such applications, as, for example, ribs in the compression core of the constrained member structure described above.

It is also possible, with regard to the compression-core structure, to provide an opening through the centre thereof, as may be required for many applications of structural elements. Such a configuration is illustrated in Figure 5 wherein a tube 41 is shown to extend through the centre of a structure having a number of members 42 maintained in fixed relation to the tube by means of ribs 43 and an outer tension skin 44 formed in the same manner as described above. In this instance, the ribs of the compression code are directed toward each other radially inward of the structure as shown in Figure 5, but do not actually intersect because of the tube 41 engaging the inner edges of the ribs. It is necessary in this type of structure to provide means for preventing relative movement between the ribs and the tube of the core, and this may be accomplished by tension windings 46 extending, for example, about two of the members and engaging the tube on opposite sides thereof. A structure formed as illustrated in Figure 5 is desirable for applications wherein it is necessary to have open passage through the centre of the structure. The interior of the compression-core tube 41 may thus be employed as a conduit for the extension of piping, wiring or the passage of fluids. This general type of structure may even be employed as a portion of an aircraft fuselage, for example, wherein the tube 41 comprises shrouding of a jet engine.

Innumerable applications of the present invention are possible. The invention may, as described, be constructed to comprise individual structural elements that may be utilized in combination for the fabrication of larger units. Thus, the constrained structure of the present invention is highly advantageous for use as beams, and columns. Alternatively, the constrained structure of the present invention may comprise a complete unit of manufacture, such as, for example, a foot bridge, a pontoon, a tower and many other possible structures. It is of course, not necessary for the constrained structure of the present invention to have a uniform cross section over the length thereof. For many applications, it is desirable to taper the structure, as illustrated, for example, at 51 of Figure 6. The members of the structure may actually come together to form a point at one or both ends of the overall structure. In this case, of course, the width of the ribs of the compression core vary along the structure, again as generally indicated in Figure 6. A variety of applications is possible for this configuration, such as, for example, towers, boat hulls and the like. It is not intended herein to indicate that the constrained structure need have any particular dimensions, for it is possible to build a structure having substantially any desired dimensions. Single units of 60′ to 100′ in length are quite readily manufactured and exhibit very remarkable strength-to-weight ratios. A 60′ unit having the configuration of the unit in Figure 6, may be readily supported at the points thereof without any noticeable sagging or deflection between ends, and yet be fully waterproofed and, in fact, air tight.

It is also to be noted that the constrained structure is equally advantageous in circumstances wherein the loads are internally applied. Thus, for example, the structures may be employed as a container wherein the volume within the tension skin is filled with any desired materials to be transported, for example. Application of forces outwardly upon the tension skin results in substantially the same resolution of forces in

the components of the structure as externally applied forces.

As briefly noted above, the members of the structures are preferably bonded to the compression core; however, this is not essential for all applications. It should furthermore be noted that when the members are bonded to the compression core allowance should be made for contraction and expansion of the member elements under load without damage to the compression core. This may be best appreciated by considering a structure such as generally illustrated in Figure 1, for example, wherein a substantial load is applied upon an upper member 11 when the unit is supported between ends of the structure, for under this condition the upper member will undergo compression while the lower members will be under tension. This results from a tendency of the structure to deflect, and consequently any individual structure is preferably designed as to individual components thereof for maximum strength under known loading conditions.

There has been described above a constrained structure in terms of particular preferred embodiments thereof; however, it is to be appreciated that many variations are possible in the structure. It is basic to the invention that the members themselves shall be constrained against any substantial movement relative to each other and this is accomplished by the provision of an inner-compression core and an outer-tension skin, both engaging the members. In order to construct a three-dimensional constrained structure, it is necessary to employ at least three members. It is, of course, not necessary that the intersection of the ribs of the compression core occur at the centre of the structure, although the most efficient transfer of forces between the ribs is achieved when the intersection is so located. It is also not necessary that the ribs of the compression core be formed as illustrated. There may, for example, be utilized a plurality of tubes disposed side-by-side and extending inwardly from the members to an intersection with the other ribs so formed. Likewise, it is possible to employ corrugated sheets as the ribs, inasmuch as it is known that such units have quite high compressive strength longitudinally of the corrugations. For particular applications of the present invention it is even possible to design the compression core in such a way that it can flex and snap back into original configuration in order to allow the overall structure to absorb impact at its skin or edges. The core may also include a central element at the joinder of the ribs or core material. Such a central element may have a high transverse compression strength to improve transfer of forces between the radial core material such as the ribs and, being fully constrained, may also be employed as a member of the overall structure in the same manner as the members outside the core. Further, for instance in the embodiments shown in Figures 1 to 3 the core ribs and members may be integrally formed, as, for example, by shaping outer rib edges to form the members.

WHAT I CLAIM IS:—

1. A constrained structure comprising a plurality of spaced apart elongated members, a compression core between the members in engagement with each of the members over the length of each and having a high compression strength inwardly thereof to prevent the members from moving toward each other, and a tension skin about the members and core and including oppositely wound helical windings of high tensile filament attached to the members to prevent the members from moving away from each other whereby the members are fully constrained from relative motion.

2. A constrained structure as claimed in claim 1, in which the core comprises a plurality of elongated ribs with one rib engaging with each member along the length thereof and the ribs being joined together along a common joinder line.

3. A constrained structure including a plurality of spaced apart elongated members, a compression core comprising a plurality of elongated ribs with one rib being integral with each elongated member along the length thereof with the ribs being joined together along a common joinder line, and a tension skin about the members and core and including oppositely wound helical windings of high tension filament attached to the members to prevent the members from moving away from each other whereby the members are fully constrained from relative motion.

4. A constrained structure as claimed in claim 2 or 3, in which there is an uneven number of members and ribs and each of the core ribs has a V-shaped inner edge for abutment with the other ribs along a common joinder whereat the ribs are affixed together.

5. A constrained structure as claimed in claim 2, 3 or 4 in which there are at least three members and the core includes the same number of ribs extending from a common joinder with substantially equal angles between ribs of the core.

6. A constrained structure as claimed in any one of the preceding claims in which the compression core includes a central tube with ribs extending radially therefrom to each of the members, and additional tension windings about the tube and at least two members.

7. A constrained structure as claimed

in any one of the preceding claims in which the compression core includes a compression plate having an elongate member engaging the compression plate and a pair of oppositely wound high-tension windings about the plate and member.

8. A constrained structure as claimed in any one of the preceding claims in which the windings of the tension skin are at an angle of between 30° and 60° to a line perpendicular to the axis of the structure.

9. A constrained structure as claimed in claim 8, in which the windings are at an angle of substantially 45° to a line perpendicular to the axis of the structure.

10. A constrained structure as claimed in any one of the preceding claims in which the windings of the tension skin are formed of flexible high-tensile-strength material joined to the members in tension.

11. A constrained structure as claimed in claim 1, which includes at least three members disposed in parallel coextensive relation, the compression core comprises the same number of ribs as there are members with the ribs being rectangular and extending outwardly for mutual engagement into separate engagement with individual members, and the tension skin covering all of the members with the windings at the ends of the structure being at a smaller angle to a line perpendicular to the axis of the structure than the remainder of the winding.

12. A constrained structure constructed and arranged substantially as described herein with reference to and as shown by Figures 1 and 2, Figure 3, Figure 4 or Figure 6 of the accompanying drawings.

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1251343 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*

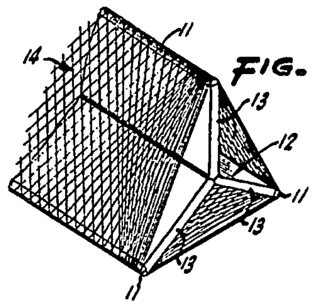
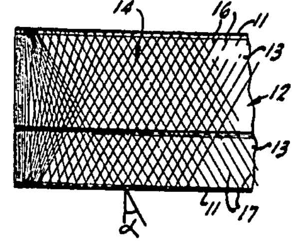


FIG. 1

FIG. 2



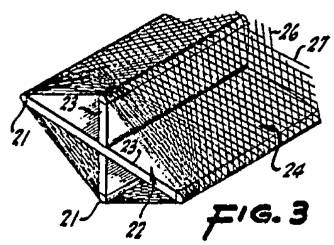


FIG. 3

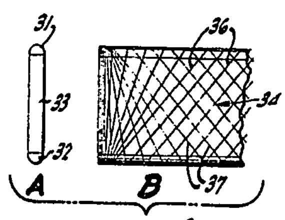


FIG. 4

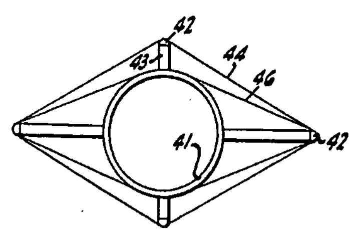


FIG. 5

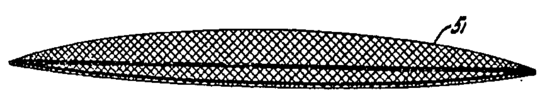


FIG. 6